# Assessing an exports effect on releases of Chinook salmon smolts from Ryde

K.B. Newman [1], May 16, 2004

The objective of the analysis described herein was to determine the degree of evidence that Ryde is affected by exports. The data used to make this assessment were the paired release data analyzed previously (Newman 2003, "Modelling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon", *Statistical Modelling* **3**:1–21).

Using the hierachical model framework (which treats survival rates and capture rates as random variables), three models were to be compared. These models are shown below *symbolically* as if they were linear regression models.

1. Model 1, Ryde is unaffected by exports, while Sacramento and Courtland are affected in the same manner by exports. This was the formulation used in Newman (2003). The symbol $\beta_i x_i$ denotes other covariates.

$$y = \beta_0 + \beta_1 Ind_{Sac} + \beta_2 Ind_{Crt} + \beta_3 (Ind_{Sac|Crt}) * Exports + \beta_i x_i \quad (1)$$

2. Model 2, Ryde is affected and in the same way as Sacramento and Courtland.

$$y = \beta_0 + \beta_1 Ind_{Sac} + \beta_2 Ind_{Crt} + \beta_3 Exports + \beta_i x_i \quad (2)$$

3. Model 3, Ryde is affected, as are Sacramento and Courtland, but potentiall to a different degree.

$$y = \beta_0 + \beta_1 Ind_{Sac} + \beta_2 Ind_{Crt} + \beta_3 Exports + \beta_4 (Ind_{Sac|Crt}) * Exports + \beta_i x_i \quad (3)$$

## Initial analysis

The hierarchical model for recoveries was fit with release-specific capture rates and no shock effect. See Newman (2003) for other variations, namely, modeling capture rates with an indicator variable for 1988 releases and allowing for a shock "mortality" at time of release. The fitting procedure is Markov chain Monte Carlo; 40,000 iterations were used and the initial 2000 were discarded for burn-in.

The results are shown in Table 1. In contrast to Model 1, which shows a negative export effect, the posterior mean for the coefficient under Model 2, which assumes a common export effect for all releases, has become positive (0.15) and over 97% of the values in the posterior distribution are positive. Thus the inclusion of Ryde releases is having a relatively influential impact on the distribution of coefficients. Evidence for Ryde releases having a positive association with exports is further strengthened in Model 3, which allows for different export coefficients for "upstream" and Ryde releases. In Model 3 the Ryde alone export coefficient has a mean of 0.53, while the mean of the export coefficient for Sacramento and Courtland releases has decreased to -0.18 compared to the -0.31 value in Model 1.

[1] K.B. Newman is Statistical Consultant, Treetops, Leven, KY8 5TF, Scotland, ken.newman2@btopenworld.com. work was completed under USFWS Purchase Order 11332-3-M057.

## Comparison with other model fitting procedures

These results are puzzling, to say the least. My *a priori* belief was that exports would have little effect, or potentially, a slight negative effect on Ryde releases, assuming that water that could have potentially reached the releases has been diverted for export. To see if similar results appeared given alternative fitting procedures, Model 3 was fit using maximum likelihood (the trinomial-binomial product model) and using pseudo-likelihood (Newman, 2003). The results, summarized in Table 2, indicate that all three models yielded positive values for the export coefficient associated with Ryde releases.

## Alternative models for Ryde and exports

Next, I considered several other explanations for the difficult to believe results. One explanation is the presence of one or more release-recovery pairs from Ryde that had exceptionally high recovery rates in a situation of high exports. There are in fact two releases from 1988 (tag codes 6-31-1 and 6-31-2) that have exceptionally high recovery rates. Figure 1 is a plot of recovery rates against exports with $R$ denoting Ryde and $U$ denoting upstream releases at Sacramento and Courtland. 1988 was a year where sampling effort was double the level of other years thus one would expect an increase in recovery rate. Note that some of the upstream releases had relatively high recovery rates, too. This picture is also confounded by release temperatures, flows and other variables that influence recovery rates.

With these considerations in mind, Model 3 was fit using an additional indicator variable for the two above 1988 releases from Ryde (this is one way of dealing with "outliers" without simply discarding them). The resulting coefficients are shown in Table 3. The magnitude of the export coefficient for Ryde releases did decrease by over 20%, but still remained large and positive.

More radical alternatives included completely new formulations of the relationship between exports and survival rates. Due to the complexity of the water dynamics and the possible outmigration paths of smolts, other alternative formulations appear reasonable, but none will be "ideal". One formulation is based on the assumption that some measure of the net flow that a smolt experiences while outmigrating which affects survival, where one measure is simply flow - exports, or better perhaps log(flow-exports), which allows for diminishing returns. Thus

$$S \propto \log(flow - exports)$$

This measure is not perfect in that the net flow experienced by an upstream release can differ depending upon whether the cross-channel gates are open and whether the fish enters the central Delta or stays in the mainstem. This thinking leads to another formulation which assumes that the effects of exports on survival differ when the cross-channel gates are open and when they are closed.

$$\begin{aligned} S[\text{Gate open}] &\propto \log(flow - exports) * I(\text{Gate open}) \\ S[\text{Gate closed}] &\propto \log(flow - exports) * (1 - I(\text{Gate open})) \end{aligned}$$

The results for this formulation are summarized in Table 4. The values for gates being open and closed match preconceptions in that when the gate is open there is a reduction in expected survival rate. However, the coefficent for Ryde releases when the gate is open is baffling in that *increases* in positive net flow lead to *decreases* in expected survival. Even including an adjustment for the two Ryde "outliers" did not change this latter result. Note, however, that the standard deviations are relatively large for the Ryde coefficients, indicative of more uncertainty than for the upstream releases.

A third, more complicated formulation is that survival is affected by exports relative to net flow, which is similar in concept to the Export to Inflow ratio which has been examined previously. One variation on this, including a gate effect:

$$logit(S[\text{Gate open}]) \approx \beta_1 \log(flow) + \beta_2 \frac{exports}{flow - exports} * I(\text{Gate open})$$

and similarly for gate closed, where $\beta_2$ "should" be negative. In other words if exports are 0, then survival increases with flow. As exports increase, there is an increasing penalty for exports; in the limit as exports approach flow, survival goes to 0, no matter what the flow. The results for this formulation are shown in Table 5. The log flow effect is essentially the same as for the original Model 3 fit. The results for upstream releases seem sensible, when the gates are closed, there is a moderately negative export effect (76% of the values in the posterior distribution are negative); conversely, with open gates, there is a strongly negative export effect. Again, however, Ryde remains puzzling, with increasing exports increasing expected survival and the gain being even larger with the gate opened.

## Comments

Estimates of coefficients for flow, salinity, and release temperature remained relatively similar under all the different scenarios and are consistent with the previously published unpaired and paired release analyses. Estimates of the coefficients for the export and gate effects on upstream releases also remain largely consistent.

The estimated effect of exports on the expected survival of Ryde releases was positive for the newly fitted models presented here. This does not seem to make sense, and various reformulations did not seem to change this basic result. One exception, the results of which were not shown here, was a model that assumed that exports *only* had an effect when flows were less than 13,000 cfs. In this case the estimated export effect is negative for both upstream and Ryde releases. This particular threshold level was based on co-plots of recovery rate against exports while controlling for flow (see Figure 2). This cut-off value was somewhat arbitrarily chosen, however, and the assumption that exports have no effects when flows exceed 13,000 cfs is even more subjective.

One important limitation of all these results, however, is that the quality of different models was not compared, not in terms of goodness of fit, nor in terms of predictive power. It turns out that the goodness of fit measures will often be much the same, due to the extreme flexibility of the hierarchical model: the random effects terms for individual release group survival and capture adapt to fit the in-river recoveries particularly well. A more definitive approach would be to predict recoveries for releases made in the years since the data that were used here were collected. Then one could empirically compare models which allow Ryde releases to be affected by exports with those that do not.

Table 1: Posterior means and standard deviations for coefficients of hierarchical model (release specific $p$ and no shock effect). The $t$ values in the last column are mean/SD for Model 3.

| | Model 1 | | Model 2 | | Model 3 | | |
|---|---|---|---|---|---|---|---|
| Variable | Mean | SD | Mean | SD | Mean | SD | "$t$" |
| Intercept | 0.59 | 0.10 | 0.58 | 0.10 | 0.69 | 0.10 | 6.72 |
| Sac | -0.56 | 0.16 | -0.41 | 0.16 | -0.61 | 0.17 | -3.55 |
| Crt | -0.02 | 0.17 | -0.11 | 0.17 | -0.10 | 0.17 | -0.60 |
| Size | 0.23 | 0.06 | 0.22 | 0.06 | 0.16 | 0.06 | 2.67 |
| Log.Flow | 0.86 | 0.12 | 0.60 | 0.13 | 0.68 | 0.12 | 5.75 |
| Salinity | 0.30 | 0.09 | 0.19 | 0.09 | 0.26 | 0.09 | 3.00 |
| RelT | -0.80 | 0.09 | -0.65 | 0.08 | -0.77 | 0.08 | -9.29 |
| HatchT | 0.00 | 0.09 | -0.18 | 0.09 | -0.15 | 0.09 | -1.73 |
| Tide | -0.04 | 0.06 | -0.06 | 0.06 | -0.08 | 0.06 | -1.46 |
| Exp (both) | NA | NA | 0.15 | 0.08 | NA | NA | NA |
| Exp.Ryde | NA | NA | NA | NA | 0.53 | 0.10 | 5.35 |
| Exp.Sac/Crt | -0.31 | 0.10 | NA | NA | -0.18 | 0.09 | -1.91 |
| Gate | -0.78 | 0.15 | -0.93 | 0.16 | -0.83 | 0.15 | -5.46 |
| Turbid | 0.38 | 0.13 | 0.59 | 0.12 | 0.45 | 0.12 | 3.60 |
| $\sigma_S^2$ | 0.14 | 0.01 | 0.14 | 0.01 | 0.14 | 0.01 | 14.90 |

Table 2: Estimated coefficients for trinomial-binomial product, pseudo-likelihood, and hierarchical versions of Models 1 and 3.

| | TBP | | PL | | Hier | |
|---|---|---|---|---|---|---|
| | M1 | M3 | M1 | M3 | M1 | M3 |
| Intercept | 1.31 | 1.27 | 1.66 | 1.50 | 0.59 | 0.69 |
| Sac | -0.68 | -0.54 | -0.79 | -0.72 | -0.56 | -0.61 |
| Crt | 0.23 | 0.01 | 0.31 | 0.46 | -0.02 | -0.10 |
| Size | -0.05 | -0.11 | -0.16 | -0.16 | 0.23 | 0.16 |
| Log.Flow | 1.40 | 1.21 | 1.63 | 1.30 | 0.86 | 0.68 |
| Salinity | 0.53 | 0.47 | 0.54 | 0.44 | 0.30 | 0.26 |
| RelT | -0.58 | -0.53 | -0.71 | -0.69 | -0.80 | -0.77 |
| HatchT | -0.34 | -0.31 | -0.37 | -0.45 | 0.00 | -0.15 |
| Tide | 0.09 | 0.09 | -0.04 | 0.15 | -0.04 | -0.08 |
| Exp.Ryde | NA | 0.22 | NA | 0.32 | NA | 0.53 |
| Exp.Sac/Crt | -0.44 | -0.29 | -0.38 | -0.21 | -0.31 | -0.18 |
| Gate | -0.77 | -0.97 | -1.19 | -1.26 | -0.78 | -0.83 |
| Turbid | 1.33 | 1.36 | 1.62 | 1.56 | 0.38 | 0.45 |

Table 3: Mean posterior coefficients for Model 3 with hierachical fitting when two Ryde releases are treated as “outliers”.

| | Original | Outlier Shift |
|---|---|---|
| Intercept | 0.69 | 0.58 |
| Sac | -0.61 | -0.47 |
| Crt | -0.10 | 0.03 |
| Size | 0.16 | 0.14 |
| Log.Flow | 0.68 | 0.66 |
| Salinity | 0.26 | 0.24 |
| RelT | -0.77 | -0.73 |
| HatchT | -0.15 | -0.13 |
| Tide | -0.08 | -0.10 |
| Exp.Ryde | 0.53 | 0.42 |
| Exp.Sac/Crt | -0.18 | -0.16 |
| Gate | -0.83 | -0.86 |
| Turbid | 0.45 | 0.48 |
| Outlier shift | NA | 1.19 |

Table 4: Mean posterior coefficients for model with log of net flow interacting with release location and gate position. The values in parentheses are standard deviations.

| | Original | Net Flow |
|---|---|---|
| Intercept | 0.69 | 0.40 (0.09) |
| Sac | -0.61 | -1.09 (0.15) |
| Crt | -0.10 | -0.29 (0.14) |
| Size | 0.16 | 0.18 (0.06) |
| Log.Flow | 0.68 | NA |
| Log(net flow):Ryde:Gate Closed | NA | 0.24 (0.20) |
| Log(net flow):Ryde:Gate Open | NA | -0.55 (0.24) |
| Log(net flow):Upper:Gate Closed | NA | 1.33 (0.16) |
| Log(net flow):Upper:Gate Open | NA | 0.82 (0.17) |
| Salinity | 0.26 | 0.23 (0.09) |
| RelT | -0.77 | -0.94 (0.09) |
| HatchT | -0.15 | 0.21 (0.09) |
| Tide | -0.08 | -0.17 (0.06) |
| Exp.Ryde | 0.53 | NA |
| Exp.Sac/Crt | -0.18 | NA |
| Gate | -0.83 | NA |
| Turbid | 0.45 | 0.53 (0.13) |

Table 5: Mean posterior coefficients for model with log flow and exports relative to net flow interacting with release location and gate position. The values in parentheses are standard deviations.

| | Original | Net Flow |
|---|---|---|
| Intercept | 0.69 | 0.14 (0.12) |
| Sac | -0.61 | -0.05 (0.17) |
| Crt | -0.10 | 0.30 (0.19) |
| Size | 0.16 | 0.11 (0.06) |
| Log.Flow | 0.68 | 0.74 (0.09) |
| Exp/(net flow):Ryde:Gate Closed | NA | 0.51 (0.24) |
| Exp/(net flow):Ryde:Gate Open | NA | 0.90 (0.24) |
| Exp/(net flow):Upper:Gate Closed | NA | -0.16 (0.21) |
| Exp/(net flow):Upper:Gate Open | NA | -0.80 (0.16) |
| Salinity | 0.26 | 0.33 (0.09) |
| RelT | -0.77 | -0.88 (0.09) |
| HatchT | -0.15 | -0.01 (0.08) |
| Tide | -0.08 | -0.12 (0.06) |
| Exp.Ryde | 0.53 | NA |
| Exp.Sac/Crt | -0.18 | NA |
| Gate | -0.83 | NA |
| Turbid | 0.45 | 0.51 (0.12) |

Figure 1: Recovery rates versus export levels. $R$ denotes Ryde and $U$ denotes upstream releases. The lines are nonparametric regression lines. Asterisks (*) mark releases made in 1988.

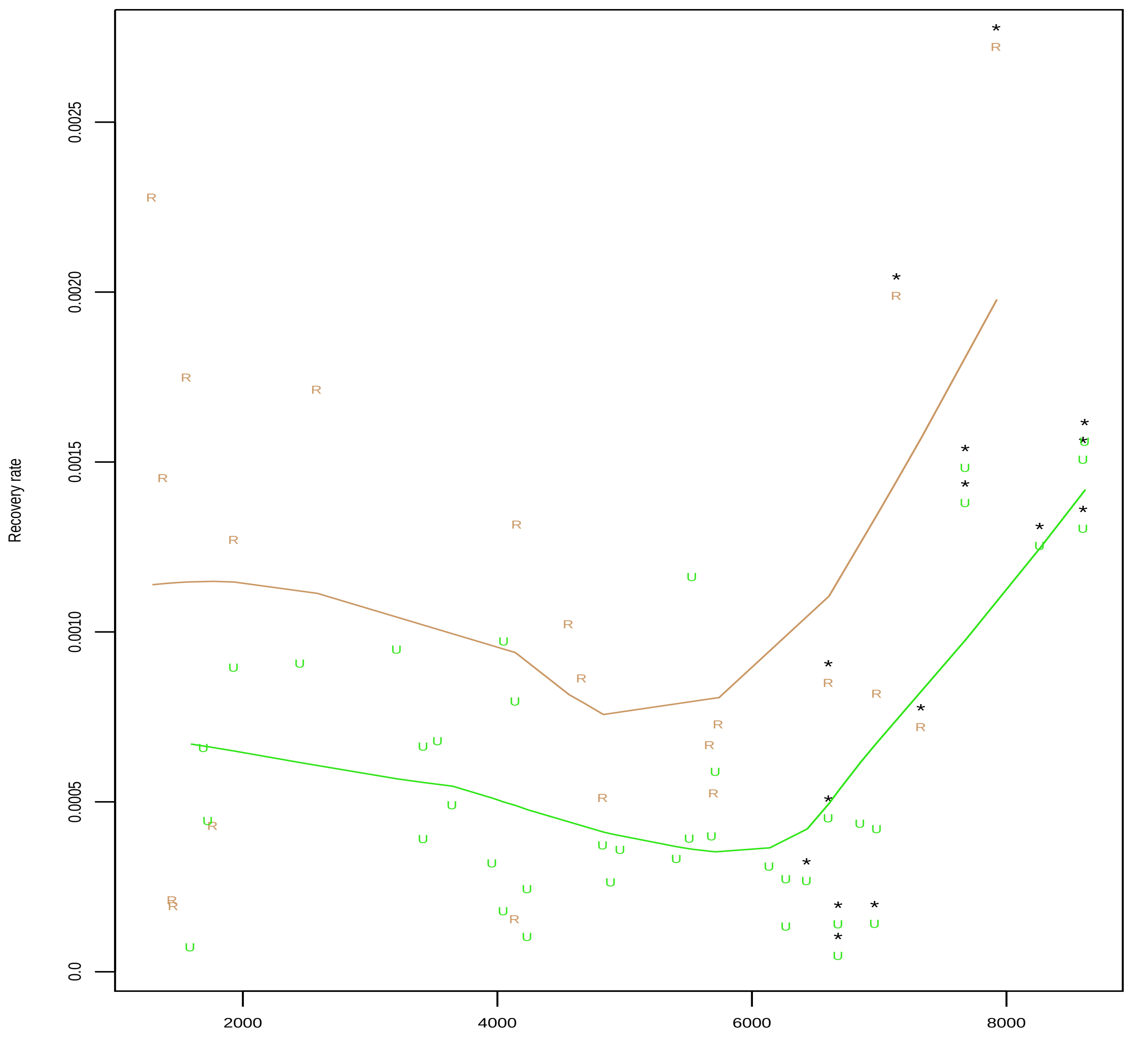

Figure 2: Co-plots of recovery rates versus export levels while controlling for flow. $R$ denotes Ryde and $U$ denotes upstream releases. The lines are nonparametric regression lines. Asterisks (*) mark releases made in 1988.